Zeitschrift: IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

Band: 13 (1973)

Artikel: Incremental collapse of thin webs subjected to cyclic concentrated loads

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DOI: https://doi.org/10.5169/seals-13765

Incremental Collapse of Thin Webs subjected to Cyclic Concentrated Loads

Rupture progressive des âmes minces soumises à des charges cycliques concentrées

Stufenweiser Kollaps von dünnen Stegen unter zyklischer Belastung durch Einzellasten

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1. Introductory Remarks

As various elements in steel structures are subjected to variable repeated loads, it was decided to investigate the deflection stability and incremental collapse of thin webs. The first study of this kind dealt with the behaviour of webs subjected to a cyclic concentrated load, this problem being encountered frequently in the design of certain types of bridge girders, crane run-way girders and similar structures. The investigation was carried out by a research team consisting of a)both authors, b) Ing.Bohdanecký, Ing.Stárek, Ing.Studničková (all three from the Structural Institute in Prague) and c) Ing.Drdácký, Ing.Kratěna and Ing.Zörnerová (from the Institute of Theoretical and Applied Mechanics in Prague).

The investigation is a continuation to another study /1/ conducted by the same research team and dealing with the post-buckled behaviour of webs subjected to static concentrated loads.

2. Test Girders and Test Set-Up

Three series of test girders were tested; their general details are given in Fig. 1 and geometrical characteristics in Table 1. An inspection of the figure and table shows that the test girders varied in a) the aspect ratio α of the web, b) the width-to-thickness ratio λ of the web, and c) the dimensions (and, consequently, in the stiffness parameter I_f/a^3t - I_f de-

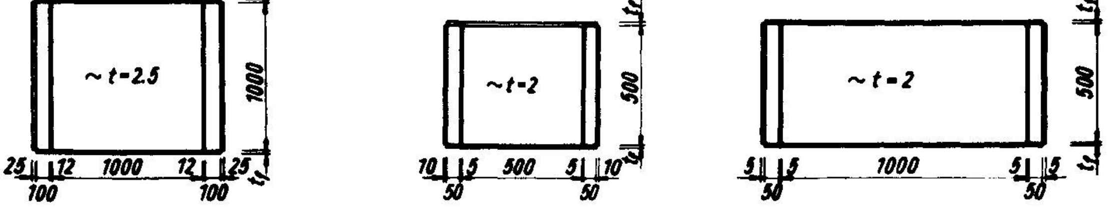

Fig. 1

Table 1

Girder	α	λ	I_f/a^3t Units of [illegible]	P_{ult} [T]
TG 1			0.887	6.5
TG 1'			0.849	5.5
TG 2			6.85	7.0
TG 3		400	28.55	8.2
TG 4			54.70	8.8
TG 5			245.38	18.0
TG 5'			238.44	18.0
PTG 1			2.17	5.0
PTG 2			2.16	4.6
PTG 3	1		64.25	5.5
PTG 4			63.48	5.6
PTG 5			237.68	7.2
PTG 6			249.33	7.0
ITG 7			2.08	4.0
ITG 8			2.08	3.7
ITG 9			2.08	3.5
ITG 10			286.98	7.4
ITG 11			297.74	7.0
PTG 12		250	0.260	3.5
PTG 13			7.51	5.8
PTG 14			7.51	4.8
PTG 15			38.13	5.9
ITG 16	2		0.257	3.5
ITG 17			0.254	3.5
ITG 18			0.260	4.0
ITG 19			7.51	5.0
ITG 20			7.51	4.7
ITG 21			38.13	6.5
ITG 22			38.13	6.0

Table 2

Girder	α	λ	I_f/a^3t Units of [illegible]	P_{ult} [T]
TG 1			0.887	5.0
TG 1'			0.849	5.5
TG 2			6.85	6.5
TG 3		400	28.55	7.0
TG 4			54.70	9.0
TG 5			245.39	18.0
TG 5'	1		238.44	18.5
STG 1			3.48	3.6
STG 2			3.50	4.0
STG 3			63.89	5.5
STG 4			64.38	5.5
STG 5			254.22	7.5
STG 6		250	242.11	8.0
STG 7			0.257	3.75
STG 8			0.254	3.5
STG 9	2		7.51	4.8
STG 10			7.51	5.25
STG 11			38.13	6.0
STG 12			38.13	5.5

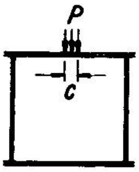

Fig. 2

noting the flange inertia, a the width of the web panel and t the web thickness) of the flanges. So it was possible to study the influence of the geometrical characteristics of the web and flanges upon the incremental collapse. In all tests the web was subjected to a narrow partial edge load (Fig.2), applied on to the upper flange at the mid-distance of the vertical stiffeners. The width of the load c=a/10, a denoting the width of the web panel.

One part of the experiments (those related to girders TG and PTG) were conducted in a pulsator, the frequency n of the cyclic load amounting to 3.3 Hz. For each loading step, 1000 loading cycles were applied. The load cycled between 0.5 T and P_i, P_i denoting various loading steps. These tests will below be referred to as "fast" cyclic tests.

As it could be argued that, in such "fast" cyclic tests, the web did not have, in individual cycles, enough time to plastify, it was decided to carry out also another group of tests with slowly cycling loads. These experiments were carried out in an Instron testing machine. The velocity of the movement of the loading beam was of 0.6 cm/min., which was about 100 times slower than the aforesaid "fast" cyclic tests. 50 loading cycles were applied for each successive loading step.

With the "fast" cyclic tests and the "slow" cyclic ones conducted, the authors were able to look also into the effect of the velocity of cycling upon the "breathing" and incremental collapse of thin webs. The reader will understand that the above adjectives "fast" and "slow" have merely a relative sense, enabling us to compare both groups of experiments with each other.

Apart from the 29 cyclic tests, the authors and their co-workers carried out 19 static experiments on test girders subjected to a static partial edge load. The geometrical characteristics of the static test girders and the experimental results are listed in Table 2. These results will be compared below to the behaviour of the girders acted on by variable repeated loads.

The authors also took the view that it was of some interest to look into two other phenomena which might play a role in the "breathing" tests. First of all it was of some importance to determine the relation of the frequency of the cyclic loads to the natural frequencies n of the test girder webs. The natural frequencies were obtained experimentally. It was found that they depended not only on the test girder dimensions, but also on the shape and magnitude of the initial curvature of the web. In all cases the values of n were greater than 20; consequently, much higher than the frequency of the applied cyclic load. The experiments were, therefore, safely in the non-resonance range.

The writers also estimated the magnitude of the dynamic inertia forces occuring as a result of the "breathing" of the web. It was concluded that these forces were small enough not to play any pronounced part in the behaviour of the webs.

3. Experimental Apparatus

The buckled pattern of the web was measured by means of a stereophotogrammetric method, which enabled the authors to take all readings in a very short time moment (0.001 sec.). The application of such a method was indispensable in our tests, in which the web and flanges were "breathing".

The stereophotogrammetric method was combined with a special device, which made it possible to take deflection readings at a given moment of a loading cycle; in particular, when, in a "breathing" cycle, the web deflection attained its maximum value. Moreover, the stereophotogrammetric method enabled us to measure not only the deflection perpendicular to the web, but also the in-plane distortion of the mesh that was marked on the web, and the deformation of the boundary frame of the web panel.

A set of strain gauges was attached to both sides of the web and of the upper flange in order the stress pattern in the girder could be studied. The strain gauges, as well as two deflection pick-ups, were linked to an automatic recorder "Ultralette". Thus it was possible to study, in terms of time, the deflection (and strain) stability when the web was breathing.

4. Deflection Stability and Incremental Collapse

As far as deflection stability is concerned, two questions needed replying:

(i) When a girder, subjected to a cyclic load, operates in the plastic range, does an increase in web deflection occur during a certain number of loading cycles?

(ii) If it is so, do these deflection increments cease after a limited number of cycles of load applications?

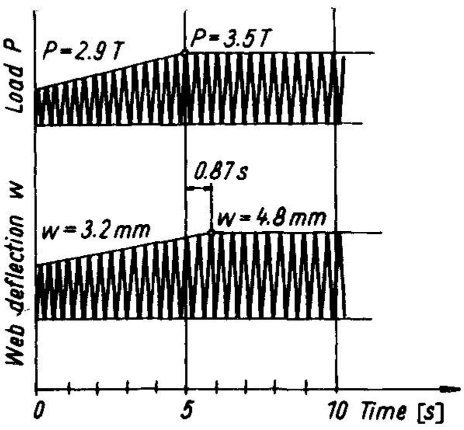

Fig. 3

Thanks to deflections and strains being measured carefully on an automatic recorder Ultralette, it was possible to give answers to the abovementioned questions.

An increase in web deflection and strain under a cyclic load was observed frequently in the plastic range of the tests. This is demonstrated in Fig. 3, in which the maximum web deflection recorded in one of the pulsator (i.e. "fast" cyclic) tests is plotted; and in Fig. 4, giving the buckled patterns of the web measured after a) the first and b) the last cycles in one loading step of an Instron (i.e. "slow" cyclic)

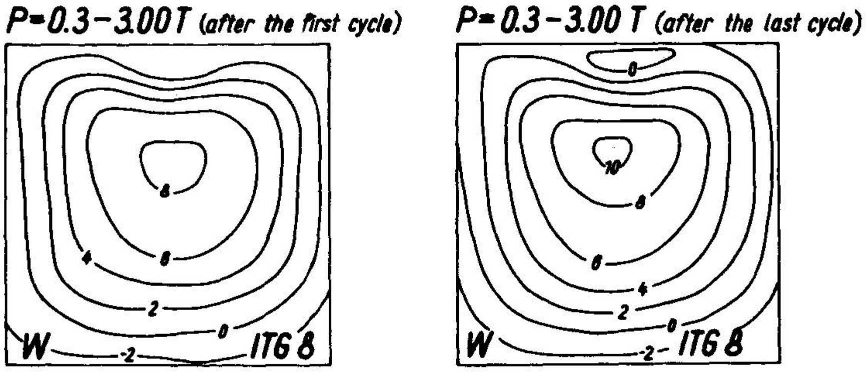

Fig. 4

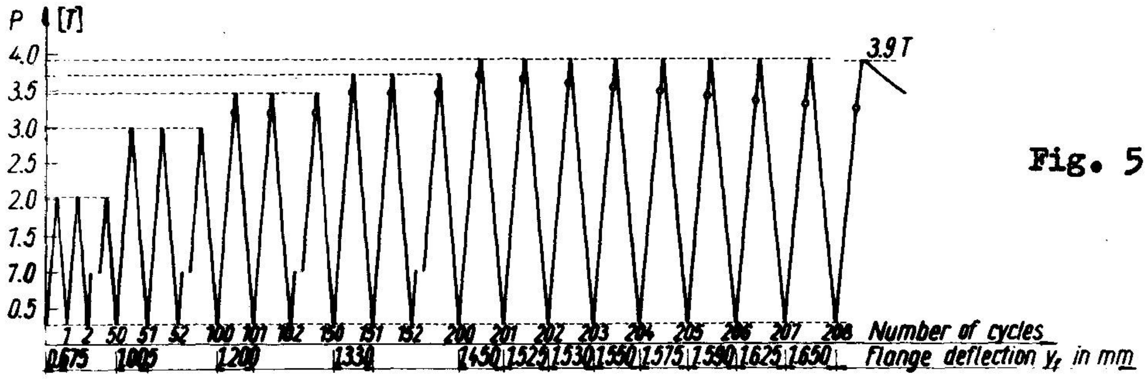

Fig. 5

experiment. The phenomenon "shook down", however, after a few (usually 3 - 5) cycles, the deflection stabilized, and the girder was able to sustain a higher load (Fig. 3). This happened for several successive loading steps; and only then the girder failed by deflection instability. This kind of failure, usually called incremental collapse, is shown in Fig. 5, presenting the load-deflection relationship measured in one of the Instron tests. The circles indicate the onset of plastification in each loading cycle.

5. Ultimate Load

The ultimate loads P_{ult} resulting from the variable repeated load tests are listed in Table 1. Some of them, the load-carrying capacities of TG-girders and α = 1-PTG-girders, are plotted (in terms of the depth-to-thickness ratio λ and the flange stiffness parameter I_f/a^3t, and in comparison with the static critical load P_{cr}) in Fig.6. An analysis of the table and figure indicates that thin webs subjected to a cyclic concentrated load manifest (see Table 2) a considerable post-buckled reserve of strength. This post-critical strength grows with the depth-to-thickness ratio of the web and with the moment of inertia of the flange.

Of particular importance was it to compare the results of the cyclic tests (Table 1) with those of the static ones (Table 2), and so give a reply to the question

(i) Whether the deflection instability and incremental collapse, discussed in par. 4, led to a reduction in ultimate strength.

Then it was of interest

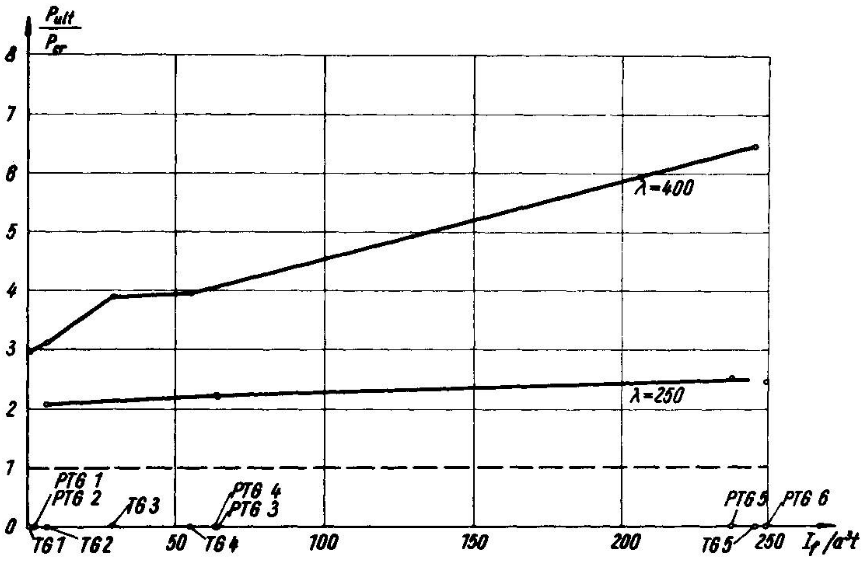

Fig. 6

(ii) To evaluate the effect of the cycling velocity upon the limiting load of the test girders.

An analysis of all results shows that

(i) In most "fast" cyclic tests, the ultimate loads were not lower than the load-carrying capacities resulting from the corresponding static experiments; and, in several cases, they were even higher.

(ii) The conclusions of the "slow" cyclic tests were similar to (i); only the number of the tests, in which the experimental load-carrying capacities were lower than the static ultimate loads, was a little greater. The corresponding reduction in ultimate load was, however, again small.

It can, therefore, be concluded that the cyclic loading and the incremental collapse did not lead to any significant reduction in ultimate strength; and, consequently, to any premature failure of the girder.

Bibliography

/1/ Škaloud M., Novák P.: Post-buckled behaviour of webs subjected to concentrated loads. Rapport Préliminaire du 9me Congrès de l'AIPC, Amsterdam, 1972.

SUMMARY

The paper deals with the deflection stability and incremental collapse of thin webs subjected to a variable repeated narrow partial edge load. An analysis of the results shows that the aforesaid phenomena did not lead to any significant reduction in ultimate strength. The ultimate loads of the test girders were also very considerably affected by the flexural rigidity of the flanges.

RESUME

Ce travail traite de la résistance à la déformation et de la ruine des âmes minces soumises à une charge variable répétée juste limitée au bord. Une analyse des résultats montre que ledit phénomène n'a pas entrainé une réduction notable de la résistance ultime. Les charges ultimes de la poutre testée ont aussi été considérablement influencées par la résistance à la flexion des semelles.

ZUSAMMENFASSUNG

Der Bericht behandelt die Deformations-Stabilität und den stufenweisen Kollaps dünner Stege unter einer veränderlichen, wiederholten linienförmigen Randlast. Eine Untersuchung der Resultate zeigt, dass das oben erwähnte Phänomen zu keiner bedeutenden Reduktion des Bruchwiderstandes führte. Die Bruchlasten der Versuchsträger wurden auch sehr stark durch die Biegesteifigkeit der Flansche beeinflusst.